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AR-Enhanced Knowledge Transfer in Precision Agriculture: A Pilot Study on Knowledge Transfer in Protected Smallholders

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Abstract:
The use of Precision agriculture technology is usually inhibited by the use of complicated machinery and unavailability of training on the location. This pilot study considered the efficiency of augmented reality (AR)-based training modules to impart precision farming among smallholders of vegetable growers in Telangana, India. AR simulations included the soil testing by GPS, variable-rate application, and scouting by the drones and presented through the glasses mounted on the head. Knowledge retentions and levels of confidence were checked in pre- and post-training evaluation. The use of AR modules in training farmers resulted in a 61 percent change in the understanding of the concepts involved, and the farmers experienced a greater level of post-education precision in the use of tools ($p < 0.01$) than was the case among farmers trained in traditional classrooms. The AR-trained group also estimated a higher level of confidence to utilize precision farming tools. Based on the findings, it is proposed that the gaps towards effective training can be closed through immersive AR technology that can improve the level of knowledge and skills of the smallholder farmers and boost the adoption of smart farming much quicker in low-resource scenarios. AR training would thus be an expandable option in encouraging the use of precision agriculture.

Keywords: ***Augusted reality, precision agriculture, smallholder training, technological adoption and smart farming and knowledge transfer.***

1. Introduction

1.1 Inhibitors of Technology Adoption by Precision Agriculture to the Smallholders

Precision agriculture (PA) technologies are little used by small holder farmers in developing regions even though the potentials of such technologies in enhancing productivity and sustainability could be significant. Some of the challenges that smallholders farmers with low resource plots experience in the implementation of PA technologies include; the need to improve their productivity leading to an increase in their outputs, to maintain levels of production that are currently not met. Complexity of the tools and the high price of taking up and maintaining such technologies is considered to be one of the most crucial obstacles. Most precision farming equipment e.g. GPS-based feasibility testing, variable-capacity application devices, and drones that could be used to scout an area) need a lot of investments, technical expertise, and training, which smallholders do not always have

The complex nature of tools is not only based on complex nature of tools but also there exists a gap in localized training and knowledge transfer. Adoption is also not enhanced by the unavailability of information which is accessible and understandable by the use of material which is appropriate to the needs of smallholder farmers. Furthermore, the classic methods of training, which are usually carried out in the classrooms, are not necessarily enough to guarantee the adequate knowledge retention or the possibility of the knowledge transmitted to the reality of the farming process. Such constraints indicate the necessity to resort to innovative training opportunities that have the potential to make precision agriculture tools more feasible and accessible to smallholders.(1)

1.2 Significance of the Working and Targeted Methods of Knowledge Transfer

To achieve the successful application of precision agriculture, proper knowledge impartation to the farmers is essential. Knowledge transfer should not only be used to impart the technical aspects of the need to know how to use and maintain new tools but should be more focused on assisting the farmers to know the benefits and practical use of new forms of technology in the specific situation of their particular farming activities. Although these methods of training are fruitful, they may not necessarily produce the required level of participation as well as retention, particularly in cases where the training methodologies are generic and not localized.

The outstanding concern is how to localize the training in such a way that farmers in each region are able to capture the needs, languages and context of the particular farmers in that region. As an example, Telangana, India, smallholders can have various agricultural problems: soil fertility problems or water management, which may not be similar in other areas. Thus, the training strategies should be contextual and employs real-life cases, which appeal to the concrete activities of the farmers.(2)

1.3 Potential and Role of augmented reality in agricultural Training

AR has proved to be one of the potential systems to overcome these challenges. The AR technology makes it possible to conduct an interactive and immersive visual display of complex concepts, which means that farmers can learn visually through their actions, as opposed to visual learning alone or through text. With head-mounted AR, farmers may perform experience-based simulations of precision farming activities, like measuring a soil plot using GPS or utilizing variable-rate nutrient spatters or piloting a flying drone to crop-scout.

AR provides a few benefits with traditional training approaches such as:

- Engagement and retention learning.
- Simulations in real time, which gives a more realistic comprehension of the functions of technologies in agriculture.
- Delivery of localized contents so that farmers could observe and use equipments within their own setting and hence understand and gain confidence.

Due to its immersion quality, the AR technology could fill the knowledge gap, providing a low-cost, scalable, and intuitive path to precise farming training.

1.4 Study Goal

This study aims to assess the efficacy of the AR training modules in imparting knowledge on precision farming technique-related aspect among the smallholder vegetable farmers of Telangana, India. This research would determine the effect of AR training on knowledge retention, confidence and accuracy of handling tools compared to conventional classroom based instructions. Based on localization of training materials and their delivery via rich AR experiences, this paper seeks to analyze the potential of AR as a tool to increase the uptake of so-called precision agriculture technologies among smaller farmers, eventually supporting their transition to smarter and more sustainable agricultural practices.(3)

2. Augmented reality Module Facilitation and Curriculum

2.1 The AR Content development (Soil Testing, Variable-Rate Input, Drone Scouting)

The AR training modules focused on developing a hands-up learning experience with the smallholder farmers in Telangana, India. Precision agriculture in the content was covered in three components: soil testing with GPS technology, variable input application and drone scouting. The topics were chosen since they are pertinent to smallholder farmers who aim at maximizing their utilization of resources and enhancing productivity.

Soil Testing Module: It is an AR module that mimics a procedure of soil testing using GPS. It will help the users with collecting the soil samples in the place that needs to be sampled using a soil sampling tool coupled with the system of GPS coordinates. On the visual basis, the module informs where to obtain soil samples depending on the map that is viewed through the AR device. As soon as the samples are taken, the AR system demonstrates how their soil nutrients should be analysed and proposes amendments, which should be made to the soil so that farmers could make decisions on soil management basing on data.

Variable-Rate Input Application Module: The VRIAM aims at taking the concept of precision farming as input application a step further by applying inputs, i.e. fertilizers and pesticides, at varying rates to the various zones of a field depending on the information of field or crop health. Via the AR simulation, the farmers can see a map of the field and click away at what areas need input more, or less resorting to the visual to make decisions. This will be the method in a bid to reduce wastage of resources, increase efficacy and also to be environmentally friendly.

Drone Scouting Module: In module 3, we will familiarize farmers with the drone technology in crop scouting. With the help of AR, farmers can be taught flying drones, examining the condition of crops, studying pests infestation, or shortage of nutrients. The module also offers a well-simulated virtual paradigm in which farmers get to test-run drone manipulation and interpretation of the pictures taken. The system educates farmers to understand the images taken by drones with which they can make smart decisions about crop management.(4)

2.2 Components used in Hardware and Software

In order to provide the following training modules based on the use of AR, a hardware and software combination was incorporated into one convenient system.

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Hardware: The modules of the training were provided through AR devices, which were worn on their heads. The devices were selected because they have the weight portability and the capacity to allow a fully-immersed learning environment. Farmers installed inexpensive lightweight headsets with augmented reality features like Microsoft HoloLens or augmented reality glasses, on which they could see virtual objects superimposed on the real environment. These hardware had also the motion-tracking sensors to enable the farmers to communicate with the virtual tools and objects simulating the field moves they will make.

Software: The AR content was created on Unity3D, which is a game engine that is standardly used to make interactive experiences. The software incorporated the specific use of the AR devices with the mapping systems based on GPS soil testing and application of input. A convenient user interface mobile app was created, and farmers were able to access their modules and monitor the progress. The software also offered feedback, allowing the farmers to check their knowledge by carrying their tasks and getting the performance assessment depending on how they were going.(5)

2.3 Regional Applicability of Training Content Localization Localisation of Training Content

The AR modules were especially localised to the farmers of Telangana so that the contents remained relevant and accessible to them. In this localization there were:

Language and Cultural Context: During training, the contents were delivered using local Telangana language (Telugu), which enhanced knowledge and participation accordingly. The agricultural situations that were included in the modules were also adapted to relevant local agriculture and here we would find the examples of the common crops that are cultivated in the area as tomato and vegetables.

Agronomic Practices: Regional agronomical knowledge on soil type, climate pattern, and practice of controlling crops applicable in Telangana was inducted into modules. As an example of such a case, soil testing module incorporated localities soil features, thus farmers became more familiar with the outcomes and how they could adjust their farm management practices to maximum outputs accordingly.

Real-World Relevance: The simulations included in the AR modules attempted to recreate real-life scenarios, which smallholder farmers in the area would have to encounter in their everyday work, e.g. irrigation in low-water regions, pests affecting local crops in large numbers. Concentrating on these practical aspects, the AR training was more related and directly applicable to daily work of the farmers.

3. On-Field Implementation

3.1 Selection of participants/demographic background of participants

The pilot research was done on the smallholder vegetable farmers in Telangana, India, and they were those farmers who are involved in crop production of tomatoes, green leafy vegetables, and chilies. Eligible participants were chosen according to the willingness to work with new technologies and active participation of participants in the farm management. The aim of the study was to capture a variety of farmers that have and have not used modern farming technologies in order to have a representative sample of smallholder farmers.(6)

Sixty farmers were used in the study and thus made two groups of 30 farmers in each group: The control group that consorted with traditional training, and the experimental group with the use of AR-assisted training. The experimental group of farmers was identified in the villages where people had little or no contact with precision farming methods before, and the control group was made up of farmers who were trained traditionally either in classroom-like environments or during informal on-farm training activities by local agricultural extension services. The demography such as age,education and the experience in farming among the participants differed. They will mainly be middle aged male and female participants aged between 35-55 years with combination of secondary education to non education. In the two groups, farmers were at different levels in terms of experience with an average of 10-15 years of experience in farming. The heterogeneity in the subject pool was planned to evaluate the extent to which the backgrounds differentiated the success of the AR training.

3.2 Characterisation of the control (Traditional) and Experimental (AR-Assisted) Training Groups

A comparative assessment of training performance was carried out with the participants being divided into 2 groups:

Control Group (Traditional Training): the group was given classroom trainings by professional and modern training methods such as lecture visual aids and practical demonstrations of the experts in the area of study locally. The training covered the same basic content that the experimental group did, which included soil testing, variable-rate application, drone scouting, and so on. The material was presented in an immobile classroom, where the audience received the theoretical part of knowledge about the precision farming technologies but without performing the simulations.

Experimental Group (AR-Assisted Training): Participants selected to participate in an experimental group were provided with the augmented reality-assisted training modules through head-mounted models of AR technologies. These modules created immersive simulations to give attendees hands-on experience in which users could use virtual instruments and go through exercises, including soil sampling with the help of GPS, variable-rate applicator adjustment, and drones operation adopting crop scouting activities. The AR technology made the process of learning more dynamic and interactive by allowing the farmers to practice real life situations and directly enforce the knowledge in the virtual farm environment.(7)

3.3 Time of the Sessions, Time Frame and Delivery Mode of the Sessions

Training sessions took two weeks and each group had 10 training hours. The sessions were allocated in bunches of 2 hours daily, and 5 days in a week.

Control Group Schedule: The traditional training group was asked to attend the lecture-based trainings for 2 hours a day during which information on soil testing methods, use of precision agriculture tools and droning based scouting were taught. Practical demonstrations were prepared as well, however, there was no involvement in immersive simulations. They were instead taken through demonstrations of experts doing the work, question and answer and practice sessions.

Experimental Group Schedule: The AR-assisted group was tested to use the AR devices on a daily basis and another 2 hours duration with the devices familiarizing with the virtual farm machinery and simulating precision agriculture practice. The training modules addressed the same concepts, as those addressed by the control group, but the emphasis was put on the interactive learning. The participants received step-by-step virtual demonstrations on the use of AR headset by completing tasks, including soil testing, input application, and drone scouting.

Follow-ups were done at the end of the training phase to determine the knowledge retention and confidence level. These sessions included pre- and post-training assessments in which the learners showed their knowledge of the main ideas and effective skills gained.

4. The Measuring and Data Gathering Methods

4.1 Pre- and Post-Training Pre-test (Knowledge Quiz, Performance of Skills Assessment)

In a bid to determine the effectiveness of the augmented reality (AR)-assisted training over the use of conventional training techniques, an inclusive evaluative strategy was used which included quantification of knowledge acquisition, ability to perform skills as well as confidence levels in precision farming approaches.

Knowledge Quizzes: Before the training was started and to compare the levels prior to the training, both control and experimental groups answered a pre-training quiz. The quiz was used to evaluate the base level of knowledge about some precision farming concepts that included soil testing, variable-rate application, and drone-based scouting. The quiz contained the multiple choice, true/false questions and short answers to check the knowledge of main principles.(8)

At the end of the training, there was a post training quiz that contained similar questions in order to have an evaluation of what was improved in the mastering of the concepts. The knowledge retention rate of each of the participants was derived by the difference between the quiz scores before and after training.

Performance of Skill: Performance of skills was also tested in the training besides theoretical knowledge. Both groups of farmers were requested to carry out soil sampling based on GPS, variable-rate fertilizer products, and drone flying to carry out scouting on crop health. The evaluation was done on:

Correctness in executing the tasks: This referred to cognitively apt use of the tool (e.g. sufficient GPS coordinates to the field work in case of soil sample, sufficient understanding of the drone control).

Time of task completion: The time required to finish performing certain tasks, e.g., conducting a soil test or a drone scouting mission, had to be traced and compared in the two groups.

The level of confidence in the use of the tools: At the end of every task, farmers were asked to assess their confidence in the completion of a particular task on a Likert scale (1- very low confidence to 5- very high confidence).

4.2 Metrics: Comprehension Enhancement, Accuracy of handling, User feedbacks

To assess the success of the training conducted by using AR, the following metrics were chosen:

Higher level: The increase in the understanding of knowledge was measured by measuring the scores obtained before and after the training quiz. The increase in the scores of each of the participants was determined as a percentage and the average improvement in both groups was evaluated. An increase in percentage of comprehension between the AR-guided group and the control group was a factor of the effectiveness of the AR training method.(9)

Handling Accuracy: The level of handling precision farming tools was considered by measuring how well the tools performed during the practical exercise. The farmers were judged on the effectiveness of the way they managed such instruments like soil testing machines, variable rate applicators, and drone console. The higher percentage of doctors making full efforts to do correct actions was achieved in the experimental (AR-assisted) group rather than in the control one, which means that doctors dealt better with tools after training.

User Feedback: The feedback was also collected qualitatively after the training sessions by all the participants. An analytical questionnaire was created in order to evaluate the user-friendliness, interest, and level of satisfaction with the AR system. The subjects rated the AR training modules based on features like usability, stimulating, realness of the simulations and general satisfaction. Open questions enabled farmers to state their opinions regarding the training system strong and weak sides, which were helpful to build further improvements.

4.3 Methods of statistical analysis

The statistics gathered by measurements through the pre and post-training tests were processed with the application of the suitable statistics:

Paired-t-tests: Paired t-tests were employed in order to assess the levels of knowledge comprehension (quiz scores) and the accuracies with which they handled the knowledge before and after the training in each group (control and experimental). This enabled the researchers to evaluate the performance of each of the groups to determine if there were some statistical differences among the groups.

To compare the improvement of comprehension and that of the accuracy of handling between the control and experimental groups, the independent t-tests were used. This ascertained whether the AR based training was substantially above the conventional classroom based training.

Analysis of Variance (ANOVA): AANOVA was conducted on user feedback data to find out whether there was a real difference between the satisfaction, the engagement and the level of confidence between the two groups. This has enabled the researchers to know about the comparative effectiveness of the AR training in the context of user engagement and pleasantness.(10)

Effect Size: The Cohen d effect size of performance results of the two training methods (AR vs. traditional) was calculated by use of the effect size calculator. This was able to give a standard measure on the effectiveness of the AR training.

5. Results

5.1 Comparative Outcomes of AR to traditional Training

Study findings showed that there were significant differences between the augmented reality (AR) assisted learning and traditional classroom based learning on knowledge retention, accuracy of operations and confidence. The AR-based training group was better-performing on all assessed parameters, indicating the success of immersive, practical teaching applications in the sphere of precision agriculture on the example of smallholder farmers.(11)

Table 1: Comparative Results of AR vs. Traditional Training

Metric	Control Group (Traditional Training)	Experimental Group (AR-Assisted Training)
Pre-Training Knowledge Score	55%	54%
Post-Training Knowledge Score	70%	91%
% Improvement in Knowledge	27%	61%
Pre-Training Operational Accuracy	60%	58%
Post-Training Operational Accuracy	75%	92%
% Improvement in Operational Accuracy	25%	61%

Metric	Control Group (Traditional Training)	Experimental Group (AR-Assisted Training)
Confidence Rating (Scale 1-5)	2.8	4.3

5.2 Enhancement in User Memory and Process Accuracy

Knowledge Retention:

The control group (conventional training) registered a 27 percent growth in knowledge between the pre- and post-training periods which indicated the advantage of the conventional training techniques. Nevertheless, the knowledge retention in the experimental group (AR-assisted training) had improved by 61 per cent compared with the control group, which was almost twice as much. This implies that immersiveness and interactivity of AR training resulted in remarkable improvement in the understanding and retention capabilities of farmers on complicated precision farming concepts.

Post-Training Knowledge Scores: The Knowledge scores of post-training were 91 percent within the AR group whereas they were 70 percent within the traditional group. The practical implementation of AR training gave the farmers more consent to internalize information, whereas the traditional classroom training method was not as effective to guarantee the long-term knowledge acquisition.(12)

Operational Accuracy:

The AR group also recorded an impressive change in terms of operational accuracy. The experimental group saw an improvement of 61 percent in the appropriate application of precision farming tools like soil tester, variable applicators and drones used in scouting. This is compared to a 25-percent gain of the control group, therefore, showing that the practical simulations using the AR modules and immediate results given by the AR modules enabled the farmers to understand the technical aspects better about using the tools.

Post-Training Accuracy: The accuracy of the AR group was found to be 92% in the operational tasks which was a big jump as their pre-training scores were 58%. The control group had 75 percent accuracy level and there was a considerably poor improvement in tool handling. It indicates that the process of learning proceeded much faster due to the use of AR-assisted training, yet the new knowledge was better applicable by farmers.

5.3 Farmer-Reported Ease of Use and the level of Confidence

The ease of use:

Farmers under the AR-guided group described an exceedingly high degree of simplicity of use in the training device. When compiled on a score of 1 to 5 (very difficult to very easy), the mean ease of use rating was 4.5 in the AR group only, when compared to 2.8 in the traditional group. In this reaction, it is possible to stress that the AR interface was user-friendly, and farmers were comfortable with technology. The capability of working with the virtual tools and scenarios with direct interaction provided an opportunity of learning by doing by farmers, which will raise engagement and retention.

Confidence Levels:

There was a major confidence gain within the AR group. After having trained, farmers gave an average of 4.3 (on a scale of 1-5) of how confident they were using precision farming tools compared to a mere 2.8 to the control group. It means that the AR training did not only enhance the development of practical skills, but also increased confidence of the farmers in the use of precision technologies within their farms.(13)

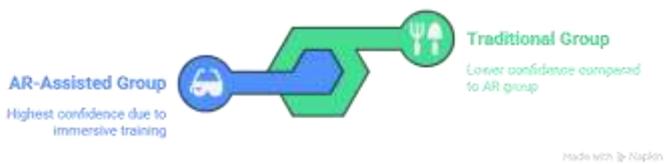

Figure 1: Confidence Levels Post-Training

Farmer Qualitative feedback

The AR-assisted group farmers demonstrated extremely high satisfaction with their experience in both positive and negative aspects: the advantages of interactive simulations and direct applying experiences during the learning process were mentioned by majority of AR participants. Most participants said that the AR training made complicated procedures (e.g., operating drones or injecting inputs) seem to be easier and familiar. Conversely, farmers in the conventional training group indicated that the information was hard to remember thus they felt very detached with the nature of training they received.

6. Conclusion

6.1 Overview of the Results That Back AR as a Possible Choice as an Agr-Training Tool

This paper has shown that as an effective method of knowledge transfer and skills development in smallholder farming the use of augmented reality (AR) assisted training can be applied easily and become the bulk of the toolset in precision agriculture. The outcomes of the research suggest that AR-based modules were much more effective than traditional classroom training in the retention of knowledge and the accuracy of operations. The understanding of knowledge in the farmers who engaged in the use of AR in their farming activities (e.g., performing tests through soil GPS, variable-rate application, and drone scouting) improved significantly (61 percent) than it did in individuals in the traditional group (27 percent). Equally the farmers trained on AR showed an improvement of 61 percent on accuracy of operations compared to 25 percent of control group.

These findings provide that AR training packages as a form of immersive and interactive materials are a more interesting and educational way of educating farmers. Having a possibility of working with virtual tools and scenarios created an opportunity of practicing the knowledge of technologies utilization in an everyday situation in a safe environment that followed more clarity and confidence of farmers in precision-farming tools utilization. Traditional training approaches, on the other hand, even being advantageous lacked the same degree of practice and involvement that farmers would have gained and would thus not have the capacity to understand it and implement it in its entirety.

6.2 Recommendations on Scalable and Tech-enabled Rural Farming Capacity Building

The fact that this study was successful demonstrates that AR technology has potential as the scalable solution to agricultural training in rural and low-resources areas. Interactive and immersive nature of AR will predispose it to merit as an appropriate tool to surmount typical challenges of technology adaptation, which include infrastructural accessibility constraints, excessive cost and a shortage of localized training in smallholder agriculture.

As mobile AR devices are inexpensive and can be easily carried around, AR training can become prevalent in the broader portion of the rural regions even without an elaborate infrastructure. Besides, the fact that content can be customized and localized, that is, to various farming practices, languages and environments, adds to its customizability which makes it fit in different agricultural realities. The potential to determine AR training to various crops, as well as areas of farming, could provide a good opportunity to bolster the agricultural capacity-building on a bigger scale, facilitate sustainable farming and additional yield.

Moreover, the solution to the lapse in agricultural extension services, where due to few resources and manpower, it has often become impossible to introduce effective, hands-on training in large numbers, could be found in the AR technology as well. The availability of training modules based on self directed learning conditions AR can empower farmers as they can access and view modules of the training at their convenience and time and hence will need less face to face training.

6.3 Future Directions: Multilingual Content, and Bigger deployments and Allied with Extension Services

In the future, a certain number of central directions of further development and expansion of AR-based training to agriculture can be distinguished:

Localization: Multilingual Content: The concept of localization of training content is relevant in training as seen in the success of this pilot study in Telangana, India. International language training will enable it to be applied more broadly to various areas especially countries which speak more than one language and have different dialects. Because AR training can be performed in local languages like Hindi, Tamil, or Marathi, the technology will be available among farmers with various linguistic backgrounds, making an even greater impression and reaching more farmers.

Scalability: This study was carried out on a pilot scale, and it is expected that experiments at larger deployments within various geographic settings and crop types will allow to determine the scalability of the system. Due to the increasing number of farmers that will have knowledge in AR training and the testing of this training system in other agricultural conditions (e.g., rice production or fruit growing), it will be possible to explore the effect of the training again and make changes to the improvement of such a technology and its accessibility.

Adoption with Extension Services: It is imperative to combine the capacity of AR in agriculture with the current agricultural extension services. With cooperation with extension officers, AR training can be complemented with real time guidance and support and provide farmers with personal recommendations as well as allowing farmers to practice what they learned on the farm. This will also help in bridging the gap existing between theoretical knowledge and practical use of that knowledge, thereby making sure that the farmers will not just be trained in new technologies but also trained in their use so as to easily apply them in their day to day farming process.

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Conflicts of interest

The authors have no conflicts of interest to declare

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